.

STUDY OF BOUNDARY LAYER PARAMETERS ON A FLAT PLATE USING WIND TUNNEL

A REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Civil Engineering

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GYANARANJAN MOHANTY

DEPARTMENT OF CIVIL ENGINEERING
NIT ROURKELA

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Under the Guidance of

Prof. A. KUMAR

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NATIONAL INSTITUTE OF TECHNOLOGY ROURKELA

2010

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the thesis entitled, "**STUDY OF BOUNDARY LAYER PARAMETERS ON A FLAT PLATE USING WIND TUNNEL**" submitted by **GYANARANJAN MOHANTY** in partial fulfillments for the award of **Bachelor Of Technology Degree** in **Civil Engineering** at **National Institute of Technology, Rourkela** (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in this report has not been submitted to any other University / Institute for the award of any Certificate.

Date: 12-05-2010

Prof. A.KUMAR
Dept. of Civil Engineering
National Institute of Technology
Rourkela - 769008

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Date: 12th May, 2010 **GYANARANJAN MOHANTY**

CONTENTS

Abstract

For the basic understanding of flow characteristics over a flat smooth plate, the experiment was carried out in the laboratory using wind tunnel. Readings of the boundary layer were taken at 15 locations over the flat plate (glass surface) with a free stream velocity (U) which varies from 13.4to 13.5 giving Reynolds number corresponding to laminar through turbulent flows. The height of the boundary layer ranges from 2mm to 29 mm .then the parameters like displacement thickness and momentum thickness were calculated from the velocity profile. The boundary layer growth over the glass plate was found out with the help of velocity profiles at different locations. The boundary layer growth gives a brief idea of fluid flow over a flat surface.

Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Boundary layer is a layer adjacent to a surface where viscous effects are important. When real fluid flows past a solid body or a solid wall, the fluid particles adhere to the boundary and condition of no slip occurs. This means that the velocity of fluid close to the boundary will be same as that of boundary. If the boundary is not moving, the velocity of fluid at the boundary will be zero. Further away from the boundary, the velocity will be increase gradually and as a result of this variation of velocity, the velocity gradient will exist. The velocity of fluid increases from zero velocity on the stationary boundary to the free stream velocity of the fluid in the direction normal to the boundary.

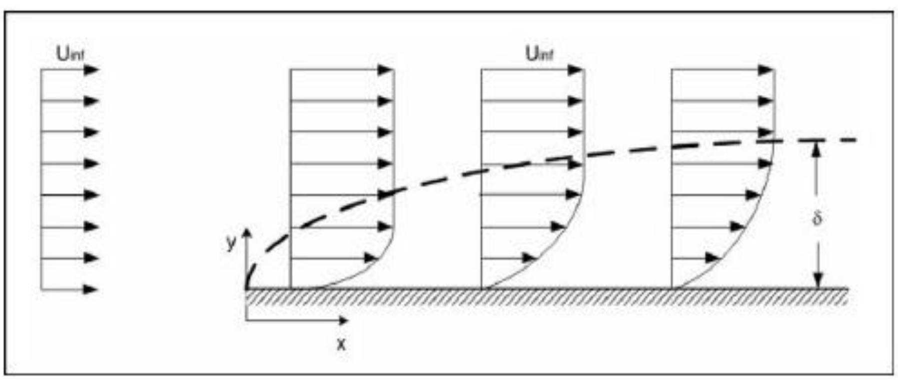


Fig 1- velocity profiles over a flat plat

Three main parameters that are used to characterize the size and shape of a boundary layer are the boundary layer thickness, the displacement thickness, and the momentum thickness**.**

The boundary-layer thickness, δ, is used for a thickness beyond which the velocity is essentially the free-stream velocity (U).

The displacement thickness is the distance by which a surface would have to be moved parallel to itself towards the reference plane in an ideal fluid stream of velocity (U) to give the same mass flow as occurs between the surface and the reference plane in a real fluid**.**

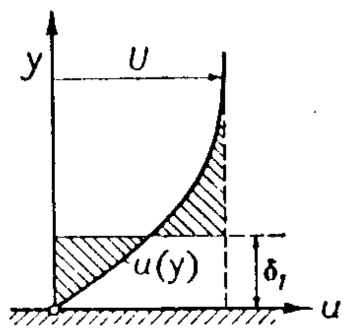


Fig 2- Dispacement thickness over a flat plate.

$$\delta^* = \int (1 - \frac{u}{u_\infty}) dy$$

The momentum thickness, θ, is the distance by which a surface would have to be moved parallel to itself towards the reference plane in an in viscid fluid stream of velocity (U) to give the same total momentum as exists between the surface and the reference plane in a real fluid**.**

$$\theta = \int \frac{u}{u_\infty}(1 - \frac{u}{u_\infty}) dy$$

The **Reynolds number** is a measure of the ratio of inertia forces to viscous forces. It can be used to characterize flow characteristics over a flat plate. Values under 500,000 are classified as Laminar flow where values from 500,000 to 1,000,000 are deemed Turbulent flow. Is it important to distinguish between turbulent and non turbulent flow since the boundary layer varies.

The factor which characterizes Reynolds numbe Re_x is the distance from the leading egde .

$$Re_x = Ux/\upsilon$$

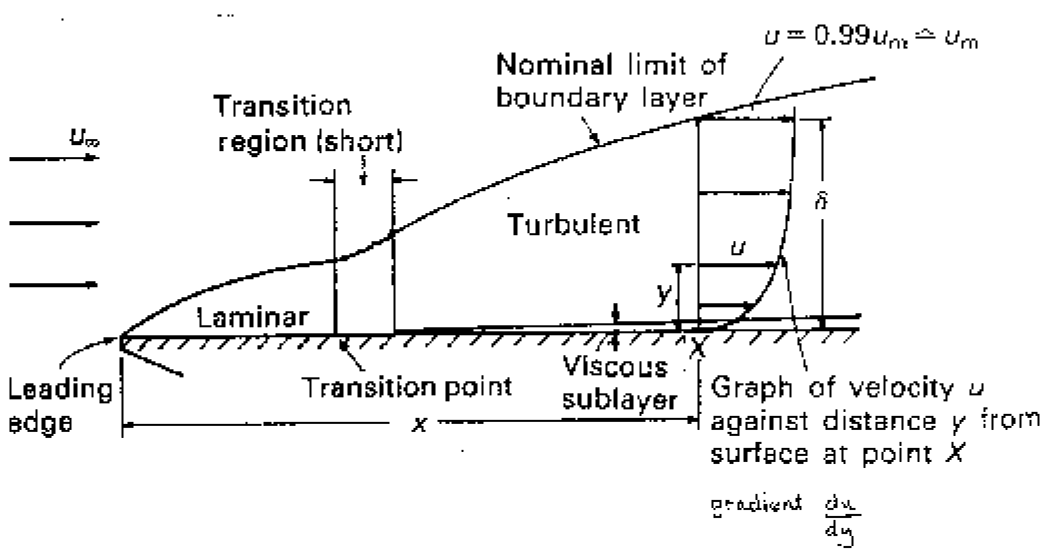


Fig 3- boundary layer over a flat plate.(y scale enlarged)

Chapter 2

LITERATURE REVIEW

2.1 CONCEPTS OF BOUNDARY LAYER

DEFINITION OF THICKNESS

The boundary layer thickness δ, as the thickness where the velocity reaches the free stream value U. The velocity in the boundary layer increases towards U is an asymptotic manner.

The displacement thickness δ* is defined as the thickness by which fluid outside the layer is displaced away from the boundary by the existence of the layer, by the streamline approaching B as shown below.

The value of velocity u within the layer is a function of distance y from the boundary as curve OA. If there was exists no boundary layer, then the free stream velocity U would persist right down to the boundary (C0).

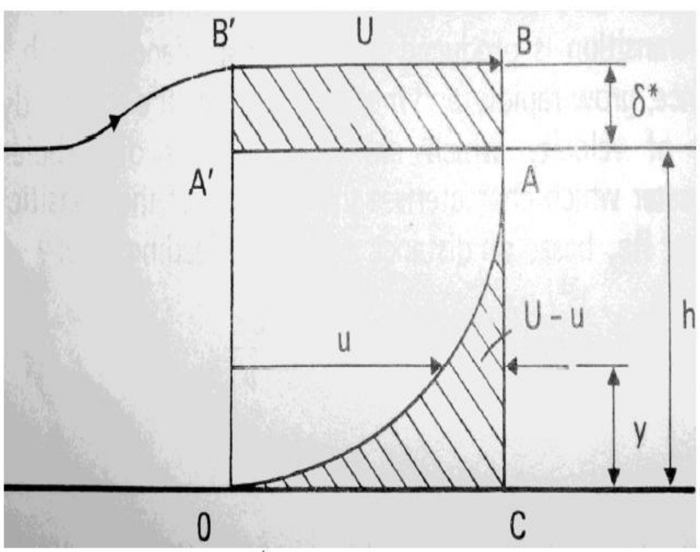


Fig 4-Boundary layer thickness

ROUGH SURFACES

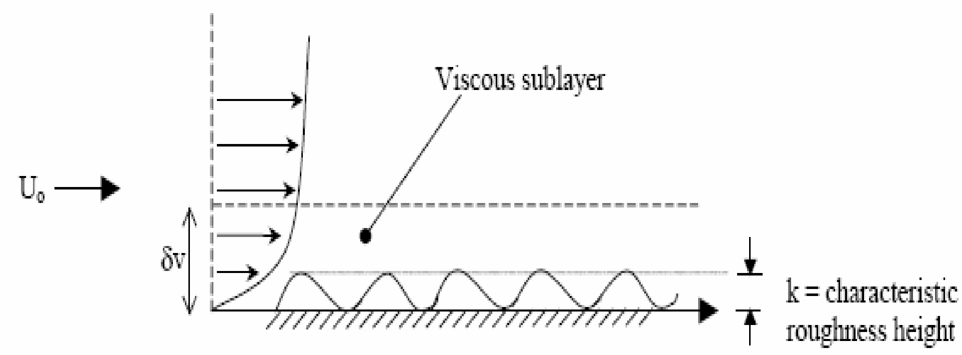


Fig-5 velocity profile on rough surface

If k is the average height of the roughness projections on the surface of the plate and δ is the thickness of the boundary layer, then the **relative roughness** (k ⁄ δ) is a significant parameter which indicates the behavior of the boundary surface.

Chapter 3

TEST APPARATUS

3.1 WINDTUNNEL

DESCRIPTION

It is a device in form of a long duct for producing a moving airstream for experimental purposes. It is used to study the effects of air moving past solid objects. The model science has assumed an important role in engineering. As it is not only makes it possible to study the behavior of the structure or machines where mathematical methods are impossible, time-consuming or inaccurate but also results in economy since it is easier and chaper to effect changes in a model rather than the prototype.

There are four essential components:

EFFUSER:-

This is placed upstream of the working section. In it the fluid is accelerated from rest to approximately at upstream end to the required conditions at the working section. The effuse contain a conversing cone, screens and other devises to refuse the turbulence and produce a uniform airstream at the exit.

WORKING SECTION:-

It is here that the model is placed is placed in the air stream leaving the downstream end of the effuser and the required observations are made. The working section consists of accessories to hold the instruments and models and devices for facilitating the motion of the model in all directions relative to airstream.

DIFFUSER:-

The function of the diffuser is to recover the kinetic energy of the airstream leaving the working section efficiently as possible.

DRIVING UNIT:-

Power is supplied continuously to maintain the flow through suction (at variable condition). This is done using a fan or propeller and a motor.

Fig 6 – The driving unit

In the laboratory, wind tunnel is an open circuit wind tunnel of the following dimensions:-

Effuser : length=1.3m
Size =2.1m*2.1m at inlet
=0.6m*0.6m at outlet

Test section : length=8m
Size =0.6m*0.6m

Diffuser section : length=5m
Size =1.3m dia outlet

Fan : dia =1.8m

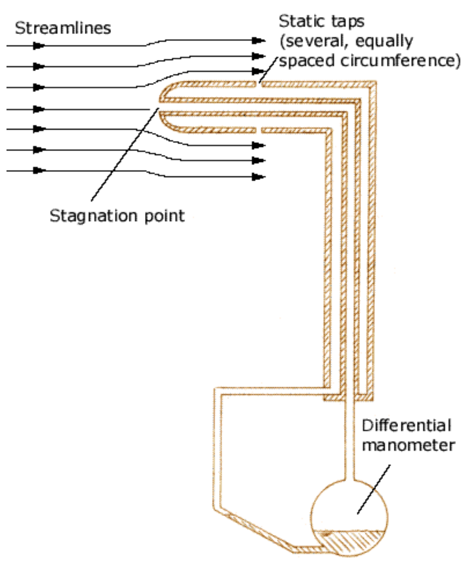
Fig 7- wind tunnel in the laboratory.

3.2 PITOT TUBE

Pitot tube is a pressure measurement instrument used to measure fluid flow velocity. The basic Pitot tube consists of a tube pointing directly into the fluid flow. As the tube contains fluid, a pressure can be measured, the moving fluid is brought to rest (stagnates) as there is no outlet to allow flow to continue. The pressure is the stagnation pressure of the fluid, also known as the total pressure or pitot pressure.

The measured stagnation pressure cannot of itself be used to determine the fluid velocity.

Bernoulli's equation states the Stagnation pressure =Static pressure + dynamic pressure



$$p_t = p_s + \left(\frac{\rho V^2}{2}\right)$$

$$V = \sqrt{\frac{2(p_t - p_s)}{\rho}}$$

Fig 8- Typical views of Pitot tube.

Where V is fluid velocity

P_t is stagnation or total pressure

P_s is static pressure

ρ is fluid density

3.3 THE MULTITUBE MANOMETER (AF10A)

The reservoir for the manometer liquid was mounted on a vertical rod so that it may be set to a convenient height. Pressures p1, p2, p3 ... in tubes 1, 2, 3 were then gauge pressures, measured relative to an atmospheric datum..The usual manometer liquid is water, although in some instances a paraffin-based liquid of low specific gravity is used. To aid visibility, the water was colored by a dye which was supplied with the equipment. To fill, the reservoir was positioned about halfway up the bar, and the fitting at the top was unscrewed. Using the funnel provided, manometer liquid was poured in until the level was halfway up the scale. Any air bubbles from the manometer tubes were then removed by tapping the inlet pipe, or by blowing into the tops of the tubes.

The manometer scale is usually graduated in millibar.

1mb=100 Pa

$\Delta p = p - p_a$

The manometer was leveled before taking readings. This was done by using the adjustable feet, while observing the spirit level and the manometer liquid levels across all of the tubes under static conditions.

Fig 9- Multi tube manometer

3.4 GLASS PLATE:

A smooth flat surface to define a clear leading edge having dimensions:

Length =100cm

Width =50.8cm

Thickness=3mm

3.4 STAND

A stand of required weight to hold the glass in a fixed position inside the test section of the wind tunnel.

Fig 10-The glass plate on the stand.

Chapter 4

TEST PROCEDURE

4. TEST PROCEDURE

1. The flat smooth surface (glass plate) was kept on a stand firmly, at the test section of the wind tunnel as shown below.

2. The wind tunnel was set up with a Pitot tube placed at 20 cm from the leading edge, attached to a multi-tube manometer to get the pressure differentials.

3. Then the wind tunnel was turned on, and the manometer was calibrated.

4. The pressure differentials readings were taken at 22 points within the boundary layer gradually

Increasing Δy (distance measured from the surface) from 1mm to 5mm.

5. The pressure difference was noted carefully,

6. The test was repeated adjusting the pitot tube at 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100 cm from the leading edge of the glass plate.

Fig 11- The experimental set up.

Chapter 5

OBSERVATONS AND CALCULATIONS

5.1 EXPERIMENTAL DATA

The total length of plate=1oocm.

Thickness of Pitot tube at tip, 2t=0.4mm.

Hence, displacement of tube centre from surface when in contact, t=0.2mm.

Values of u/U are found from equation given below:

$$(u/U) = \sqrt{(P_t/P_o)}$$

Where P_t is Pitot Pressure and P_o is the Pitot tube reading in the free stream.

The Free Stream Velocity is then obtained by the equation given below:

$$(1/2)\ \rho U^2 = P_0$$

The Reynolds Number is then obtained by the equation given below:

$$Re = UL/\upsilon$$

The basic assumptions used in the following calculations are:

1. The working fluid, air, was an incompressible fluid as the testing was done in the low speed wind tunnel.
2. A standard atmospheric condition of the air is assumed.

Table 1-Nomenclature:

ρ	Air density
u	Velocity at sections
U	Free stream velocity
υ	Kinematic viscosity
μ	Dynamic viscosity
ΔP	Pressure difference
L	Length of the plate
y	Distance from the surface
Re	Reynolds number
x	Distance from the leading edge
δ	Boundary thickness
δ^*	Displacement thickness
θ	Momentum thickness

5.2 EFFECTIVE CENTRE

The effective center equation is used to measure the first Δy distance on which data is taken at each location.

Thickness of Pitot tube at tip, 2t=0.4mm.

Hence, displacement of tube centre from surface when in contact, t=0.2mm

5.3 FREE STREAM VELOCITY

The reading recorded were in millibar pressure was converted to Pascal .the free stream velocity requires Pascal pressure which was calculated .the free steram velocity was found out with the use of formula.

$$U=\sqrt{(2*\Delta P/ \rho_{air})}$$

Applying the above formula, the free stream velocity was calculated as 13.44m/s.

5.4 REYNOLDS NUMBER

After calculating the free stream velocity at all the sections of the plate,the Reynolds number was determined using the formula.

$$Re = \frac{\rho x}{\mu}$$

The distance from the leading edge was measured at which boundary layer distributions were evaluated and given in the Table

5.5 DISPLACEMENT THICKNESS

The displacement thickness at all the points of the pitot tube is given by the equation()**.**After getting the free stream velocity and the velocity at different y distance from the surface, displacement thickness was calculated. The following formula is used to get a linear approximation of the displacement thickness at all Pitot tube locations:

$$\boldsymbol{\delta = \sum (1\text{-}u/U)\ \Delta y}$$

5.6 MOMENTUM THICKNESS

The momentum thickness at all the locations of the Pitot tube is given by the equation()

The linear approximation of momentum thickness was calculated using the formula:

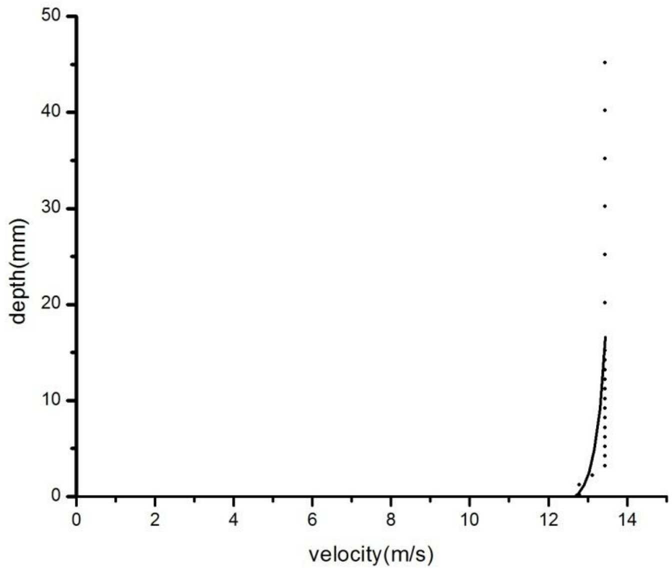
$$\boldsymbol{\theta = \sum (u/U)\ (1\text{-}u/U)\ \Delta y}$$

5.7 TABLES AND GRAPHS

All the results of displacement thickness, momentum thickness at all points are given in the table

TABLE 2- Distance of 20cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	12.78671	0.95119
1.2	12.78671	0.95119
2.2	13.11889	0.9759
3.2	13.44286	1
4.2	13.44286	1
5.2	13.44286	1
6.2	13.44286	1
7.2	13.44286	1
8.2	13.44286	1
9.2	13.44286	1
10.2	13.44286	1
11.2	13.44286	1
12.2	13.44286	1
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 1- Depth v/s Velocity at 20cm from the leading edge

Parameters calculated

Boundary layer thickness δ =2.78 mm

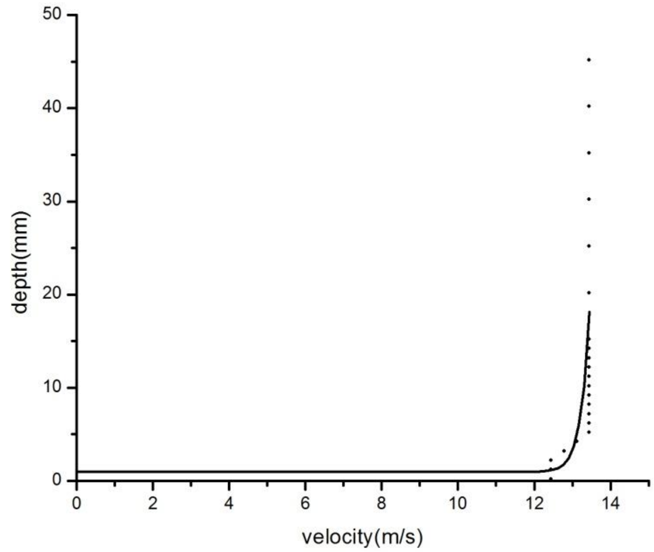
Displacement thickness δ *=0.121353mm

Momentum thickness θ =0.11674mm

Reynolds number= 175000

Table 3-Distance of 25cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	12.44567	0.92582
1.2	12.44567	0.92582
2.2	12.44567	0.92582
3.2	12.78671	0.95119
4.2	13.11889	0.9759
5.2	13.44286	1
6.2	13.44286	1
7.2	13.44286	1
8.2	13.44286	1
9.2	13.44286	1
10.2	13.44286	1
11.2	13.44286	1
12.2	13.44286	1
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 2-Depth v/s Velocity at 25cm from the leading edge

<u>Parameters calculated</u>

Boundary layer thickness δ = 4.785mm

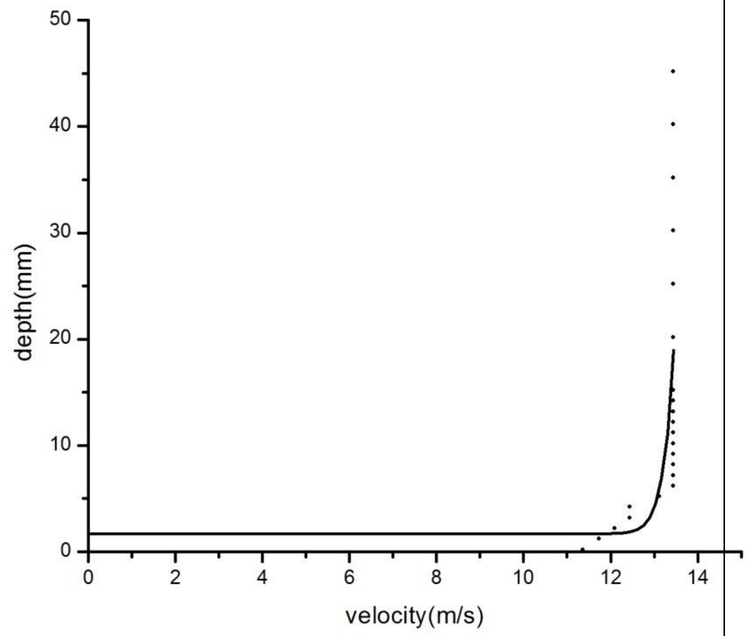
Displacement thickness δ *=0.524459

Momentum thickness θ =0.494587

Reynolds number= 219400

Table 4-Distance of 30cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	11.3629	0.845154
1.2	11.73389	0.872872
2.2	12.09502	0.899736
3.2	12.44567	0.92582
4.2	12.44567	0.92582
5.2	13.11889	0.9759
6.2	13.44286	1
7.2	13.44286	1
8.2	13.44286	1
9.2	13.44286	1
10.2	13.44286	1
11.2	13.44286	1
12.2	13.44286	1
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 3-Depth v/s Velocity at 30cm from the leading edge

<u>Parameters calculated</u>

Boundary layer thickness δ = 5.785mm

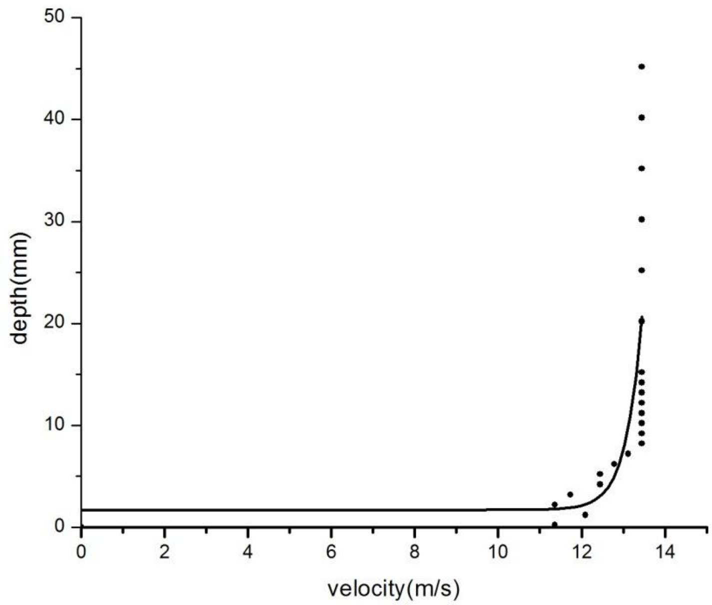
Displacement thickness δ *=1.07832mm

Momentum thickness θ =0.988274mm

Reynolds number= 263200

Table 5-Distance of 35cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	11.36129	0.845154
1.2	12.09502	0.899735
2.2	11.36129	0.845154
3.2	11.73389	0.872872
4.2	12.44567	0.92582
5.2	12.44567	0.92582
6.2	13.11889	0.95119
7.2	13.44286	0.9759
8.2	13.44286	1
9.2	13.44286	1
10.2	13.44286	1
11.2	13.44286	1
12.2	13.44286	1
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 4-Depth v/s Velocity at 35cm from the leading edge

Parameters calculated

Boundary layer thickness δ =7.78mm

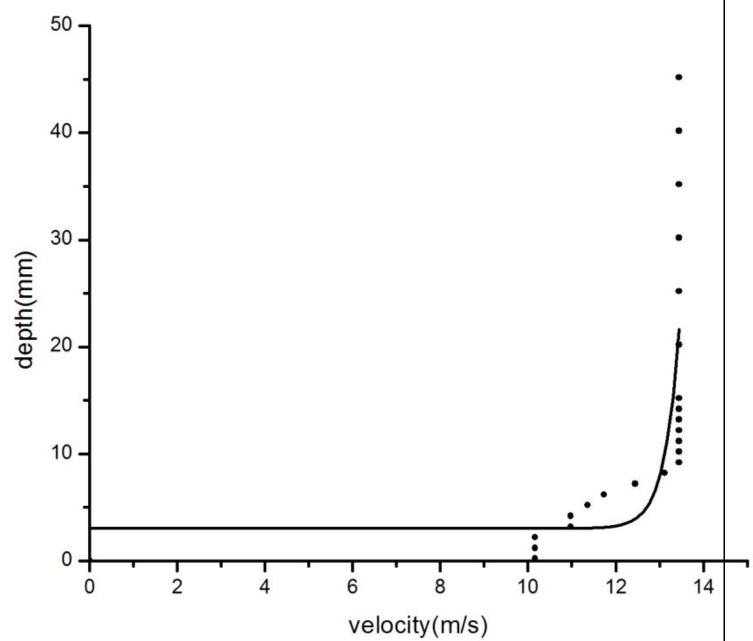
Displacement thickness δ *=2.072192mm

Momentum thickness θ =1.880188mm

Reynolds number= 307000

Table 6-Distance of 40cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.16185	0.755929
1.2	10.16185	0.755929
2.2	10.16185	0.755929
3.2	10.97605	0.816497
4.2	10.97605	0.816497
5.2	11.36129	0.845154
6.2	11.73389	0.872872
7.2	12.44567	0.92582
8.2	13.11889	0.9759
9.2	13.44286	1
10.2	13.44286	1
11.2	13.44286	1
12.2	13.44286	1
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Grap5-Depth v/s Velocity at 40cm from the leading edge

Parameters calculated

Boundary layer thickness δ = 8.785mm

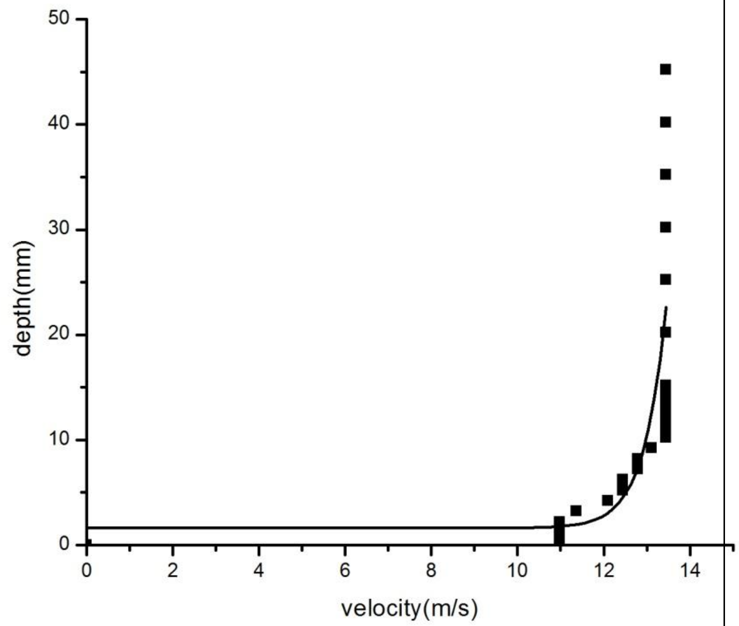
Displacement thickness δ *=4.561689mm

Momentum thickness θ =3.828785mm

Reynolds number= 351000

Table 7-Distance of 45cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.97605	0.816497
1.2	10.97605	0.816497
2.2	10.97605	0.816497
3.2	11.36129	0.845154
4.2	12.09502	0.899735
5.2	12.44567	0.92582
6.2	12.44567	0.92582
7.2	12.78671	0.95119
8.2	12.78671	0.95119
9.2	13.11889	0.9759
10.2	13.44286	1
11.2	13.44286	1
12.2	13.44286	1
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 6-Depth v/s Velocity at 45cm from the leading edge

Parameters calculated

Boundary layer thickness δ = 9.78mm

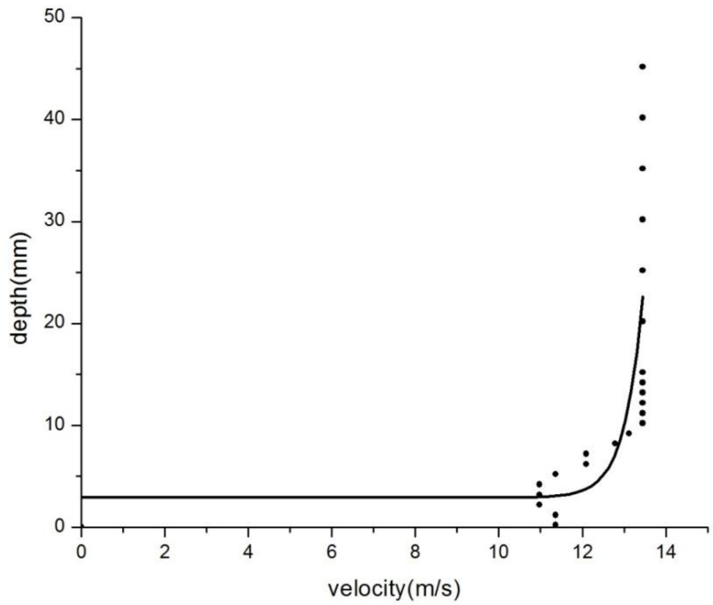
Displacement thickness δ *=3.396277mm

Momentum thickness θ =3.05134mm

Reynolds number= 394000

Table 8-Distance of 50cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	11.36129	0.845154
1.2	11.36129	0.845154
2.2	10.97605	0.816497
3.2	10.97605	0.816497
4.2	10.97605	0.816497
5.2	11.36129	0.845154
6.2	12.09502	0.899735
7.2	12.09502	0.899735
8.2	12.78671	0.95119
9.2	13.11889	0.9759
10.2	13.44286	1
11.2	13.44286	1
12.2	13.44286	1
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 7-Depth v/s Velocity at 50cm from the leading edge

Parameters calculated

Boundary layer thickness δ = 9.785mm

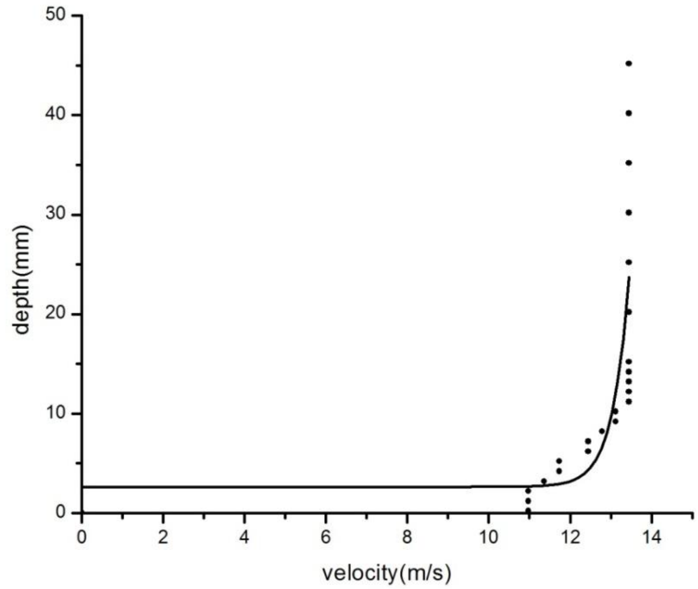
Displacement thickness δ *=4.7449123mm

Momentum thickness θ =4.108018mm

Reynolds number= 438800

Table 9-Distance of 55cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.97605	0.816497
1.2	10.97605	0.816497
2.2	10.97605	0.816497
3.2	11.36129	0.845154
4.2	11.73389	0.872872
5.2	11.73389	0.872872
6.2	12.44567	0.92582
7.2	12.44567	0.92582
8.2	12.78671	0.95119
9.2	13.11889	0.9759
10.2	13.11889	0.9759
11.2	13.44286	1
12.2	13.44286	1
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 8-Depth v/s Velocity at 55cm from the leading edge

Parameters calculated

Boundary layer thickness δ = 10.78mm

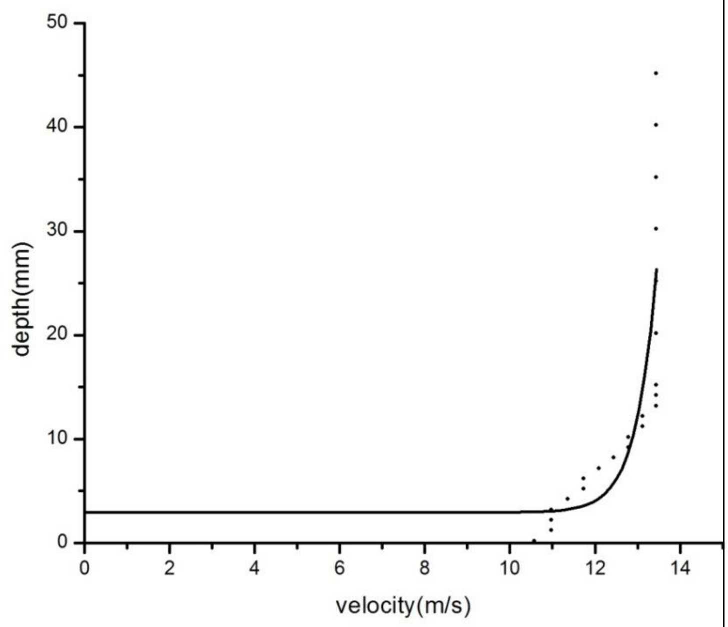
Displacement thickness δ *=4.212919mm

Momentum thickness θ =3.758508mm

Reynolds number= 482650

Table 10-Distance of 60cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.57679	0.786796
1.2	10.97605	0.816497
2.2	10.97605	0.816497
3.2	10.97605	0.816497
4.2	11.36129	0.845154
5.2	11.73389	0.872872
6.2	11.73389	0.872872
7.2	12.09502	0.899735
8.2	12.44567	0.92582
9.2	12.78671	0.95119
10.2	12.78671	0.95119
11.2	13.11889	0.9759
12.2	13.11889	0.9759
13.2	13.44286	1
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 9-Depth v/s Velocity at 60cm from the leading edge

Parameters calculated

Boundary layer thickness δ = 12.78mm

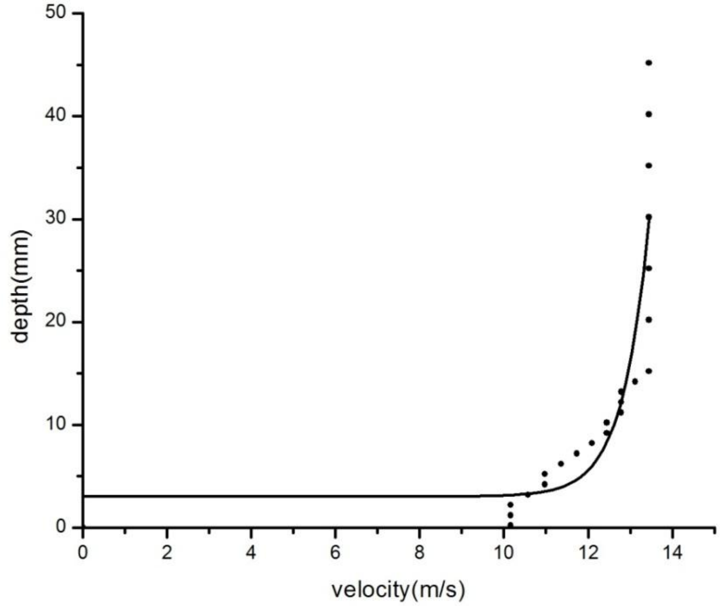
Displacement thickness δ *=6.194417mm

Momentum thickness θ =5.50082mm

Reynolds number= 526500

Table 11-Distance of 65cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.16185	0.755929
1.2	10.16185	0.755929
2.2	10.16185	0.755929
3.2	10.57679	0.786796
4.2	10.97605	0.816497
5.2	10.97605	0.816497
6.2	11.36129	0.845154
7.2	11.73389	0.872872
8.2	12.09502	0.899735
9.2	12.44567	0.92582
10.2	12.44567	0.92582
11.2	12.78671	0.95119
12.2	12.78671	0.95119
13.2	12.78671	0.95119
14.2	13.11889	0.9759
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 10-Depth v/s Velocity at 65cm from the leading edge

<u>Parameters calculated</u>

Boundary layer thickness δ = 14.785mm

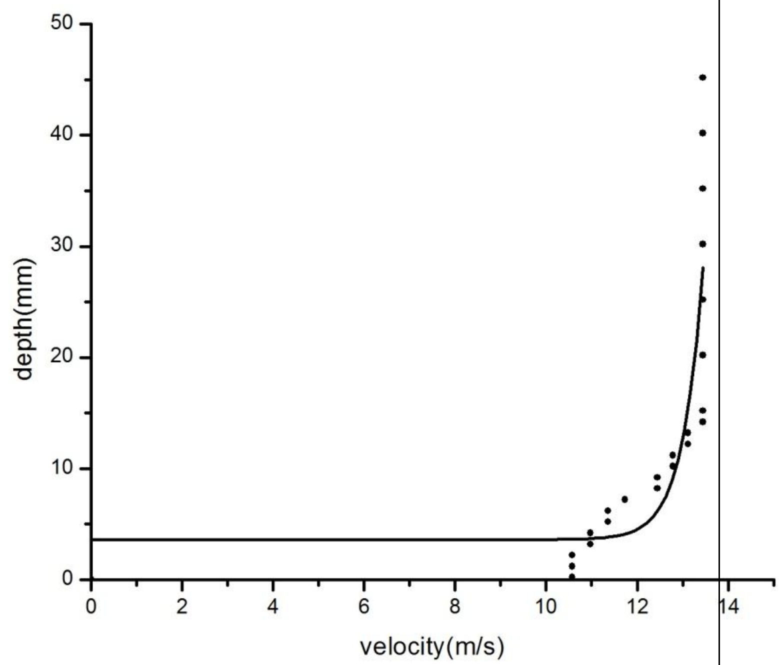
Displacement thickness δ *=9.551143mm

Momentum thickness θ =8.325045mm

Reynolds number= 570400

Table 12-Distance of 70cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.57679	0.786796
1.2	10.57679	0.786796
2.2	10.57679	0.786796
3.2	10.97605	0.816497
4.2	10.97605	0.816497
5.2	11.36129	0.845154
6.2	11.36129	0.845154
7.2	11.73389	0.872872
8.2	12.44567	0.92582
9.2	12.44567	0.92582
10.2	12.78671	0.95119
11.2	12.78671	0.95119
12.2	13.11889	0.9759
13.2	13.11889	0.9759
14.2	13.44286	1
15.2	13.44286	1
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 11-Depth v/s Velocity at 70cm from the leading edge

<u>Parameters calculated</u>

Boundary layer thickness δ = 13.785mm

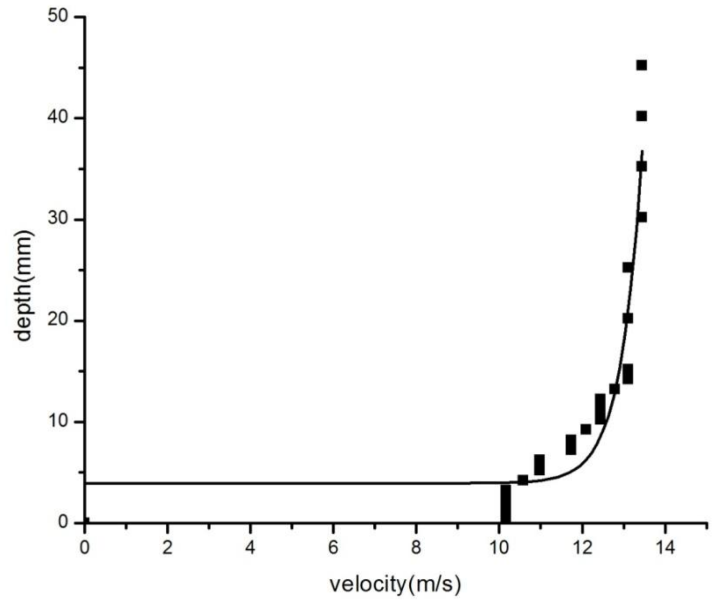
Displacement thickness δ *=7.753434mm

Momentum thickness θ =6.789421mm

Reynolds number = 614300

Table 13-Distance of 75cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.97605	0.816497
1.2	10.97605	0.816497
2.2	10.97605	0.816497
3.2	10.97605	0.816497
4.2	11.36129	0.845154
5.2	11.73389	0.872872
6.2	11.73389	0.872872
7.2	12.44567	0.92582
8.2	12.44567	0.92582
9.2	12.78671	0.95119
10.2	13.11889	0.9759
11.2	13.11889	0.9759
12.2	13.11889	0.9759
13.2	13.11889	0.9759
14.2	13.11889	0.9759
15.2	13.11889	0.9759
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 12-Depth v/s Velocity at 75cm from the leading edge

<u>Parameters calculated</u>

Boundary layer thickness δ =18.125mm

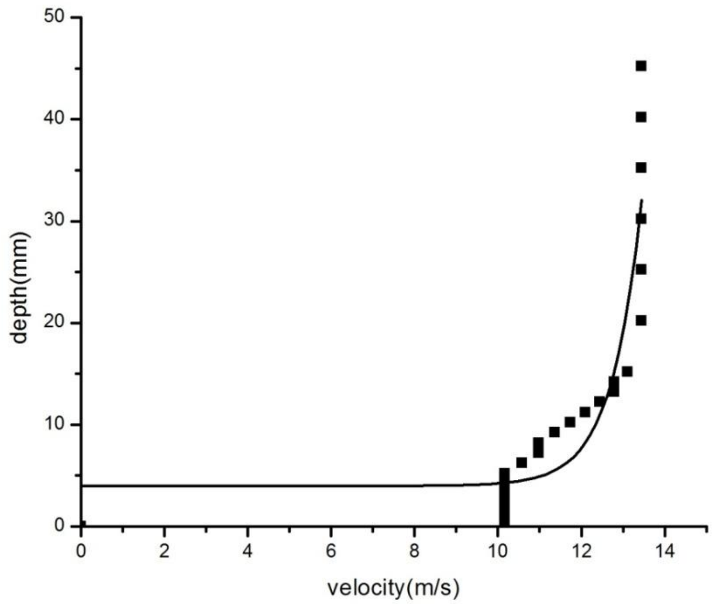
Displacement thickness δ *=6.775278mm

Momentum thickness θ =6.110434mm

Reynolds number= 658000

Table 14-Distance of 80cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.16185	0.755929
1.2	10.16185	0.755929
2.2	10.16185	0.755929
3.2	10.16185	0.755929
4.2	10.57679	0.786796
5.2	10.57679	0.786796
6.2	10.97605	0.816497
7.2	11.36129	0.845154
8.2	11.36129	0.845154
9.2	11.73389	0.872872
10.2	12.09502	0.899735
11.2	12.09502	0.899735
12.2	12.44567	0.92582
13.2	12.78671	0.95119
14.2	12.78671	0.95119
15.2	13.11889	0.9759
20.2	13.44286	1
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 13-Depth v/s Velocity at 80cm from the leading edge

Parameters calculated

Boundary layer thickness δ =18.125mm

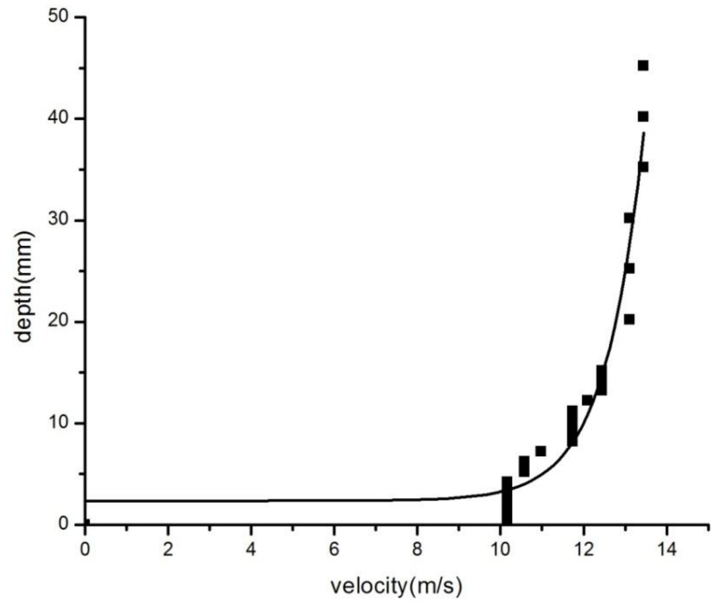
Displacement thickness δ *=13.11011mm

Momentum thickness θ =11.19465mm

Reynolds number= 702000

Table 15-Distance of 85cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.16185	0.755929
1.2	1016185	0.755929
2.2	10.16185	0.755929
3.2	10.16185	0.755929
4.2	10.16185	0.755929
5.2	10.57679	0.786796
6.2	10.57679	0.786796
7.2	10.97605	0.816497
8.2	11.73389	0.872872
9.2	11.73389	0.872872
10.2	11.73389	0.872872
11.2	11.73389	0.872872
12.2	12.09502	0.899736
13.2	12.44567	0.92582
14.2	12.44567	0.92582
15.2	12.44567	0.92582
20.2	13.11889	0.9759
25.2	13.11889	0.9759
30.2	13.11889	0.9759
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 14-Depth v/s Velocity at 85cm from the leading edge

Parameters calculated

Boundary layer thickness δ = 33.125mm

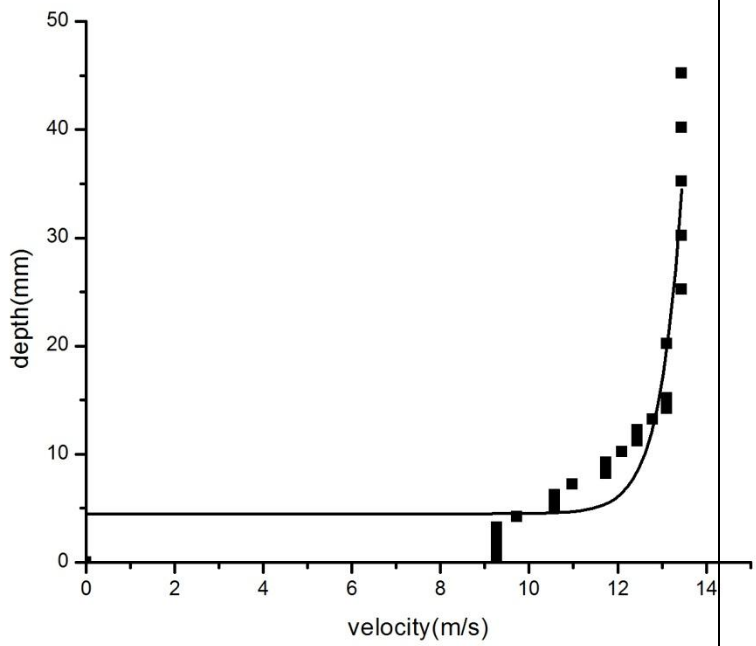
Displacement thickness δ *=17.57433mm

Momentum thickness θ =15.13037mm

Reynolds number= 745900

Table 16-Distance of 90cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	9.276456	0.690066
1.2	9.276456	0.690066
2.2	9.276456	0.690066
3.2	9.729229	0.723747
4.2	9.729229	0.723747
5.2	10.57679	0.786796
6.2	10.57679	0.786796
7.2	10.97605	0.816497
8.2	11.73389	0.872872
9.2	11.73389	0.872872
10.2	12.09502	0.899736
11.2	12.44567	0.92582
12.2	12.44567	0.92582
13.2	12.78671	0.95119
14.2	13.11889	0.9759
15.2	13.11889	0.9759
20.2	13.11889	0.9759
25.2	13.44286	1
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 15-Depth v/s Velocity at 90cm from the leading edge

<u>Parameters calculated</u>

Boundary layer thickness δ = 23.125mm

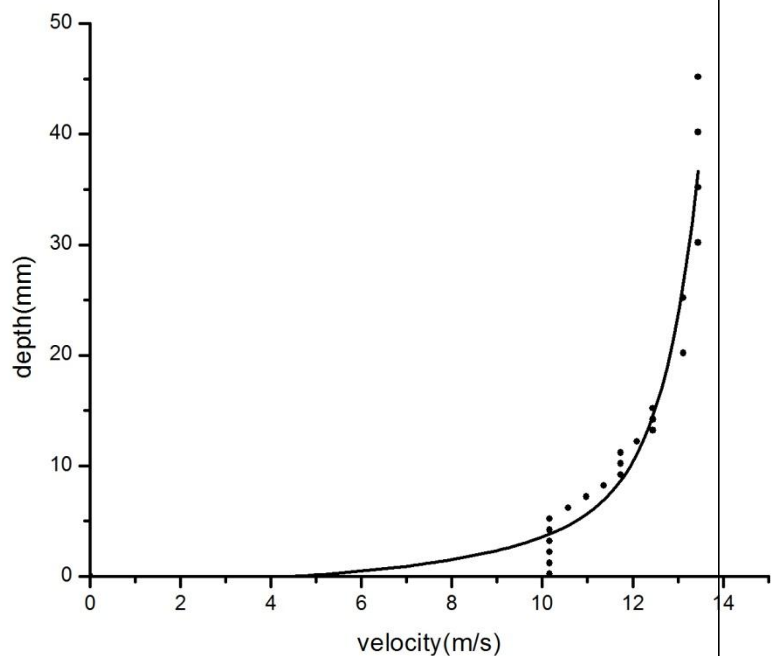
Displacement thickness δ *=13.72195mm

Momentum thickness θ =11.47798mm

Reynolds number= 789800

Table 17-Distance of 95cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	10.16185	0.755929
1.2	10.16185	0.755929
2.2	10.16185	0.755929
3.2	10.16185	0.755929
4.2	10.16185	0.755929
5.2	10.16185	0.755929
6.2	10.57679	0.786796
7.2	10.97605	0.816497
8.2	11.36129	0.845154
9.2	11.73389	0.872872
10.2	11.73389	0.872872
11.2	11.73389	0.8728720
12.2	12.09502	0.899736
13.2	12.44567	0.92582
14.2	12.44567	0.92582
15.2	12.44567	0.92582
20.2	13.11889	0.9759
25.2	13.11889	0.9759
30.2	13.44286	1
35.2	13.44286	1
40.2	13.44286	1
45.2	13.44286	1



Graph 16-Depth v/s Velocity at 95cm from the leading edge

Parameters calculated

Boundary layer thickness δ = 28.125mm

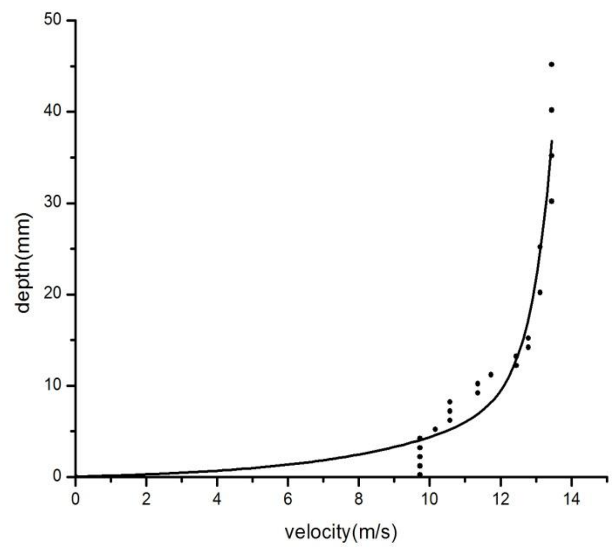
Displacement thickness δ *=17.2343mm

Momentum thickness θ =14.6704mm

Reynolds number= 833600

Table 18-Distance of 100cm from the leading edge

Distance From the surface,mm	Velocity (m/s),u	u/U
0	0	0
0.2	9.729228887	0.723747
1.2	9.729228887	0.723747
2.2	9.729228887	0.723747
3.2	9.729228887	0.723747
4.2	9.729228887	0.723747
5.2	10.16184815	0.755929
6.2	10.5767869	0.786796
7.2	10.5767869	0.786796
8.2	10.5767869	0.786796
9.2	11.36129162	0.845154
10.2	11.36129162	0.845154
11.2	11.73389153	0.872872
12.2	12.44567141	0.92582
13.2	12.44567141	0.92582
14.2	12.78671185	0.95119
15.2	12.78671185	0.95119
20.2	13.11888956	0.9759
25.2	13.11888956	0.9759
30.2	13.44286154	1
35.2	13.44286154	1
40.2	13.44286154	1
45.2	13.44286154	1



Graph 17-Depth v/s Velocity at 100cm from the leading edge

<u>Parameters calculated</u>

Boundary layer thickness δ = 28.125mm

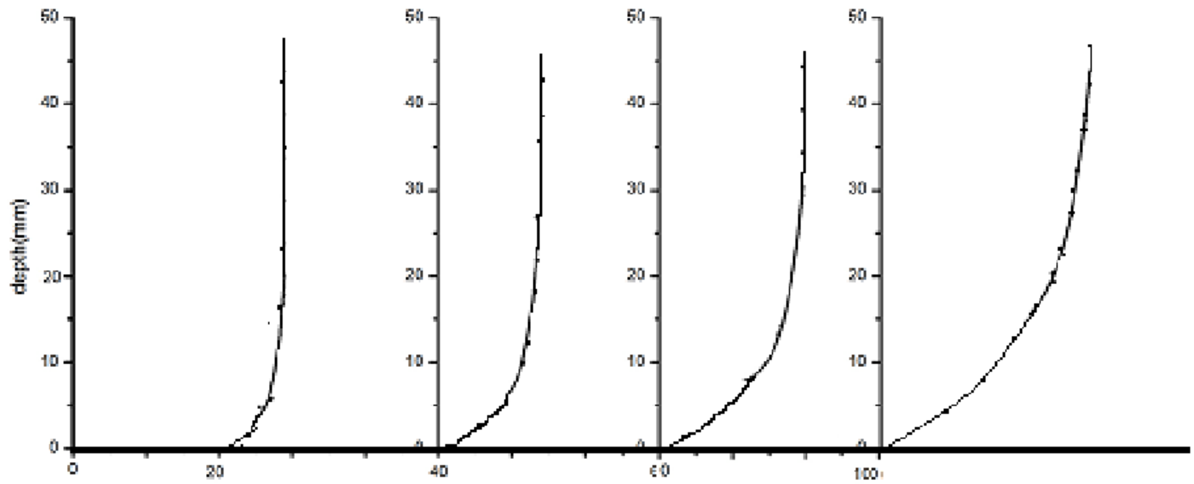
Displacement thickness δ *=17.75434mm

Momentum thickness θ =14.74mm

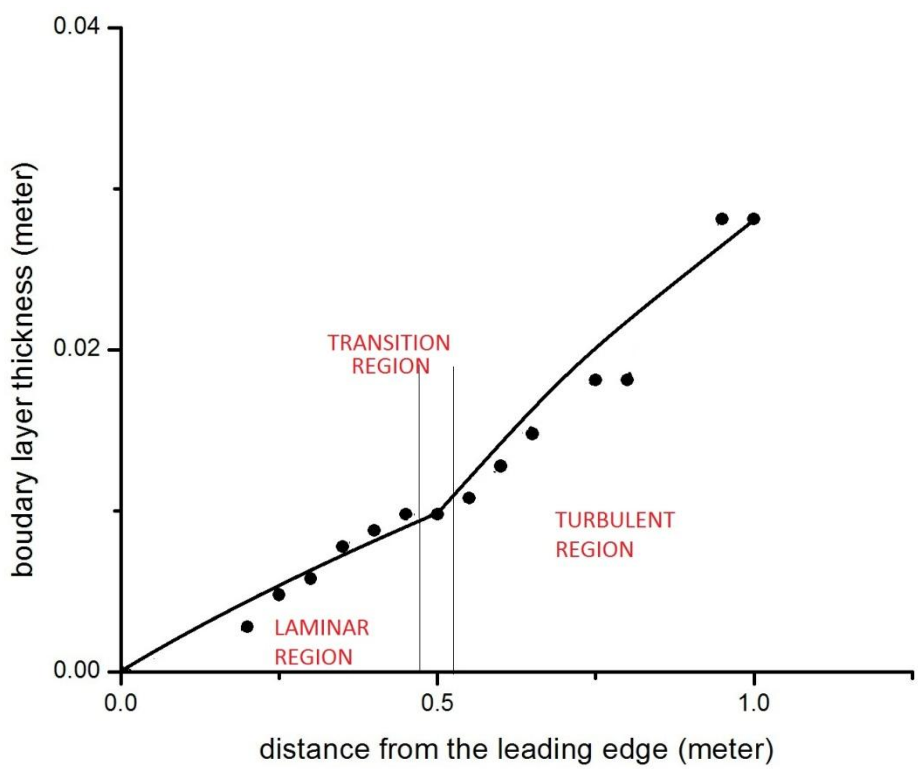
Reynolds number= 877000

Table 19- Reynolds number and flow type , displacement thickness, momentum thickness, boundary layer thickness as function of x.

Sl. No.	X(m)	Reynolds number	Flow type	Displacement thickness(mm)	Momentum thickness(mm)	Boundary layer thickness(mm)
1	0.2	1.75×10^5	Laminar	0.121	0.11674	2.78
2	0.25	2.19×10^5	Laminar	0.5244	0.4945	4.785
3	0.30	2.63×10^5	Laminar	1.07	0.988	5.785
4	0.35	3.07×10^5	Laminar	2.072	1.88	7.78
5	0.40	3.51×10^5	Laminar	4.56	3.828	8.785
6	0.45	3.94×10^5	Laminar	3.396	3.05	9.78
7	0.50	4.38×10^5	Laminar	4.749	4.108	9.785
8	0.55	4.82×10^5	Laminar	4.213	3.758	10.78
9	0.60	5.26×10^5	Transition	6.1944	5.5008	12.78
10	0.65	5.70×10^5	Turbulent	9.5511	8.325	14.785
11	0.70	6.14×10^5	Turbulent	7.7534	6.789	13.125
12	0.75	6.58×10^5	Turbulent	6.7752	6.11	18.125
13	0.80	7.02×10^5	Turbulent	13.11	11.194	18.125
14	0.85	7.45×10^5	Turbulent	17.574	15.13	19.785
15	0.90	7.89×10^5	Turbulent	13.72	11.477	23.125
16	0.95	8.34×10^5	Turbulent	17.2343	14.67	28.125
17	1.00	8.77×10^5	Turbulent	17.754	14.7409	28.125



Graph 18-Velocity profiles at 20cm, 40cm, 60cm, and 100cm from the leading edge.



Graph 19-The boundary layer growth along the length.

Chapter 6

DISCUSSIONS AND RESULTS

6 DISCUSSIONS AND RESULTS

1. The Reynolds number shows that the flow transitioned from laminar to turbulent flow (Re>500,000) after 55 cm from the leading edge of the plate surface. The Reynolds number is largely a function of speed, viscosity and density of the fluid.
2. The boundary layer thickness is in the range of 2-29 mm, which was expected for the low speed wind tunnel.
3. The table (19) shows that the thickness increases along the length of the plate.
4. The graph (19) shows the boundary layer thickness v/s length of the plate which give a clear idea of the boundary layer growth along the plate and also the boundary layer grows as the length is increased and tends to have great tangent as the velocity increases.
5. The graph(18) shows that the velocity profiles changes along the length of the glass plate. Initially the velocity profiles have steeper gradient compared to the velocity profiles at end ones.

Chapter 7

CONCLUSIONS

7 CONCLUSIONS

- Test conducted on a flat plate gave a better understanding of boundary layers and there parameters. As the wind tunnel is an open tunnel, readings were taken very carefully to avoid error in the measurement and analysis.
- The boundary layer growth which was found out experimentally matched the theoretical graph.
- The velocity profiles gave a clear view of variation which took place along the length of the glass plate.
- The flow transitioned from laminar to turbulent through transition region. The laminar region and the turbulent region were easily differentiated but it was difficult to get the transition region from the graph

Chapter 8

REFERENCES

8 REFERENCES

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